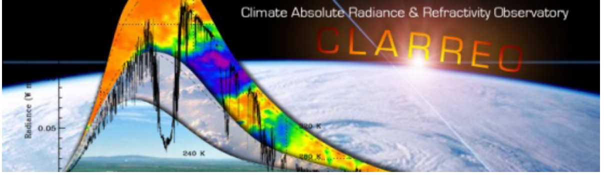

VIIRS Reflective Solar Bands Calibration Updates

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CLARREO SDT Meeting, NASA GSFC, January 7-9, 2014

Outline

- CLARREO Related Activities
- VIIRS Reflective Solar Bands (RSB) and On-orbit Calibration
- 2-Year On-orbit Performance (S-NPP VIIRS RSB)
  - Solar Diffuser and Solar Diffuser Stability Monitor
  - RSB Detector Responses from SD and Lunar Calibration
  - Detector SNRs
- Summary

CLARREO Related Activities

- CLARREO Reflective Solar (RS) Calibration Uncertainty
  - Methodology and UC assessment tool development (internal technical report)
- Calibration Inter-comparison
  - Aqua MODIS and S-NPP VIIRS
  - Improve RS on-orbit calibration reference
- Importance of CLARREO to GSICS and other Missions
  - Jim Butler and Jack Xiong represented NASA at the 14th meeting of the GSICS Executive Panel at the Japan Meteorological Agency in Tokyo, Japan, July 15-16, 2013
  - Jack Xiong represented NASA at the GSICS Research Working Group meetings and user workshops (D. Doelling from LaRC also actively involved)
  - To brief current status of CLARREO while maintaining the project's international visibility, interest, and importance
- Publications
  - 1 paper on sensitivity study of RS sensor spectral range, sampling, and frequency (TGRS submitted)
  - 1 paper on VIIRS early on-orbit calibration (inter-comparison) performance (JGR in press)

Continued Importance of CLARREO to GSICS

-The scope of the Global Space-based Inter-calibration System (GSICS): to define, share and implement community-agreed best practices, standards, procedures and tools for optimizing the calibration of operational meteorological, climate and other environmental space-based observation instruments.

-GSICS recognizes that initiatives such as CLARREO and TRUTHS will provide hyperspectral instruments whose measurements are directly traceable to SI standards *in orbit*. These would provide critical benchmark observations for climate monitoring and absolute reference instruments for satellite inter-calibration.

← ***14th GSICS Executive Panel meeting participants***

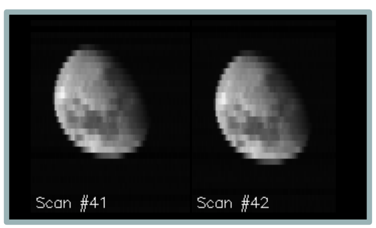
***15th GSICS Executive Panel meeting scheduled for May 16-17, 2014 at the China Meteorological Agency in Guangzhou, China*.**

VIIRS Reflective Solar Bands

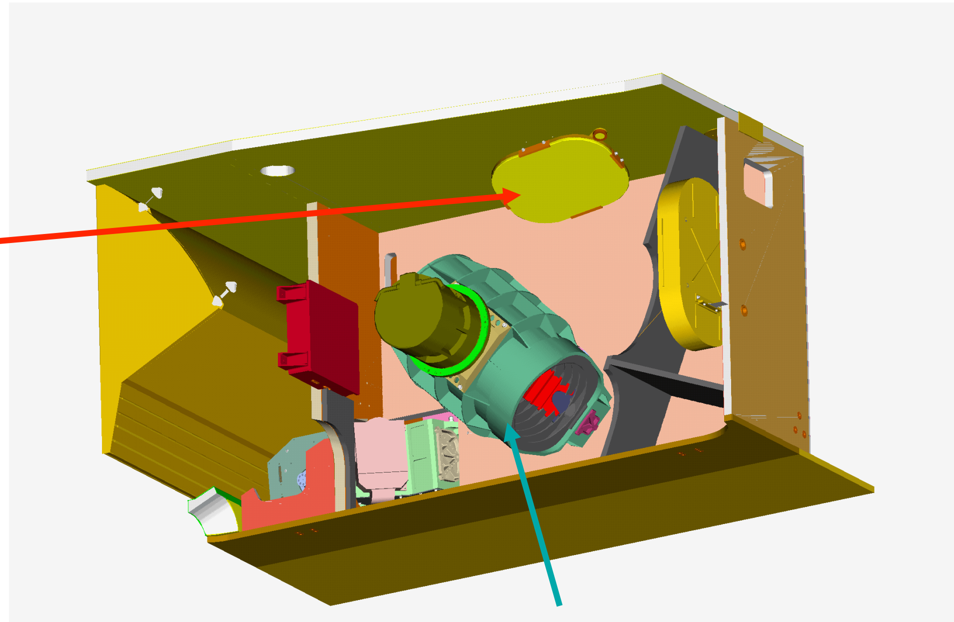
- Visible Infrared Imaging Radiometer Suite (VIIRS)
  - S-NPP VIIRS (F1) was launched on October 28, 2011 (SDR Cal/Val Review in Dec. 2013)
  - JPSS 1 VIIRS (F2) has nearly completed the sensor-level ambient test (launch in 2017)
  - JPSS 2 VIIRS (F3) is currently being built by the sensor vendor (launch in 2022)
- Heritage instruments: AVHRR, OLS, SeaWiFS, MODIS
- Spectral range: 22 bands between 0.4 µm and 12.5 µm
  - 16 moderate (radiometric) bands (M1-M16); 5 imaging bands (I1-I5), and 1 day/night band (DNB)
  - Dual gain bands: M1-M5, M7, and M13 (7 bands)
  - **Reflective solar bands (RSB): M1-M11, I1-I3, and DNB**
- Spatial resolution: 375 m for I-bands and 750 m for M-bands and DNB
- Swath: 3040 km (daily global coverage)
- On-board calibrators (MODIS heritage): SD, SDSM, and BB
- VIS/NIR, SMIR, and LWIR focal plane assemblies (FPA)
- Pixel aggregations (along-scan direction) and bowtie deletion (edge of scan)

On-orbit Calibration (RSB)

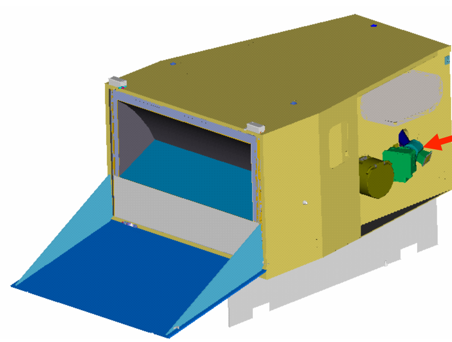
Solar Diffuser

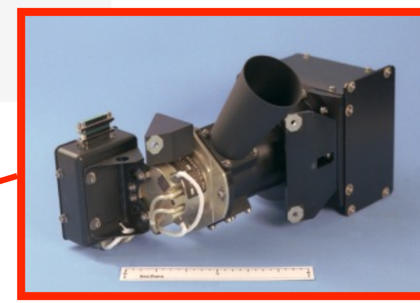


Moon in SV



Rotating Telescope Aft Optics and HAM





Solar Diffuser Stability Monitor

Reflective Solar Bands Calibration Using SD and SDSM

On-orbit Operation and Calibration

- **Key Events (operation/calibration activities)**
  - **Launch: 10/28/11**
  - **Instrument turn-on: 11/8/11**
  - **Nadir door open: 11/21/11 (first image from VIS/NIR)**
  - **Cryo-cooler door open: 1/18/12 (observations from all bands)**

  - **BB warm-up/cool-down: started from 2/6/12 (quarterly, 8 since launch)**
  - **SD calibration performed each orbit**
  - **SDSM operated on a daily basis**

  - **Roll maneuvers: started from 1/4/12 (near-monthly, 17 since launch)**
  - **Yaw maneuvers; 2/15/12 – 2/16/12 (SD/SDSM screen transmission)**
  - **Pitch maneuvers: 2/20/12 (TEB response versus scan angle)**

RSB Solar Calibration

RSB Calibration F and H Factors

1/F: Detector Gain;
H-Factor: SD Degradation

$$L_{EV} = F \cdot \left(c_0 + c_1 \cdot dn_{EV} + c_2 \cdot dn_{EV}^2\right)$$

$$L_{SD\_Meas} = F \cdot \left(c_0 + c_1 \cdot dn_{SD} + c_2 \cdot dn_{SD}^2\right)$$

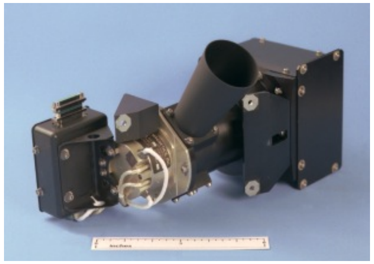
$$L_{SD\_Comp} \propto BRDF_{SD}(t) \cdot \tau_{SDS}$$

$$F = \frac{L_{SD\_Comp}}{L_{SD\_Meas}}$$

$$BRDF_{SD}(t) = H_{SD}(t) \cdot BRDF_{SD}(t_0)$$

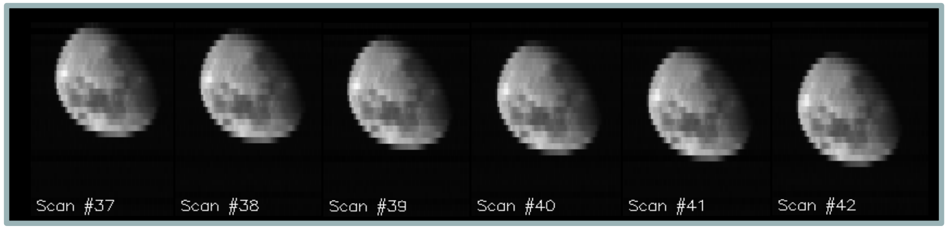
$$H_{SD}(t) = H(t) / H(t_0)$$

$$H(t) \propto \frac{dc_{SD} \cdot \tau_{SDSMS}}{dc_{SUN} \cdot \tau_{SDS}}$$



The dn and dc are VIIRS and SDSM detector "corrected" responses

RSB Lunar Calibration



Multiple scans of I1 lunar images (Jan 4, 2012)

- Integrated lunar irradiance (or radiance)

$$J(B,M,G) = \sum_{s,d} [c_0(B,M,G) + c_1(B,M,G)dn(s,d) + c_2(B,M,G)dn(s,d)^2]$$

  - *B*: Band; *M*: HAM side; *G*: Gain stage; *d*: Detector; *s*: Sub-frame
  - dn: Background subtracted response
  - c_0, c_1, and c_2: calibration coefficients

- Relative lunar F-factor

$$F(B,M,G) = J_{Model}(B) / J_{sensor}(B,M,G)$$

  - Lunar model (ROLO) predication provided by Tom Stone (USGS)

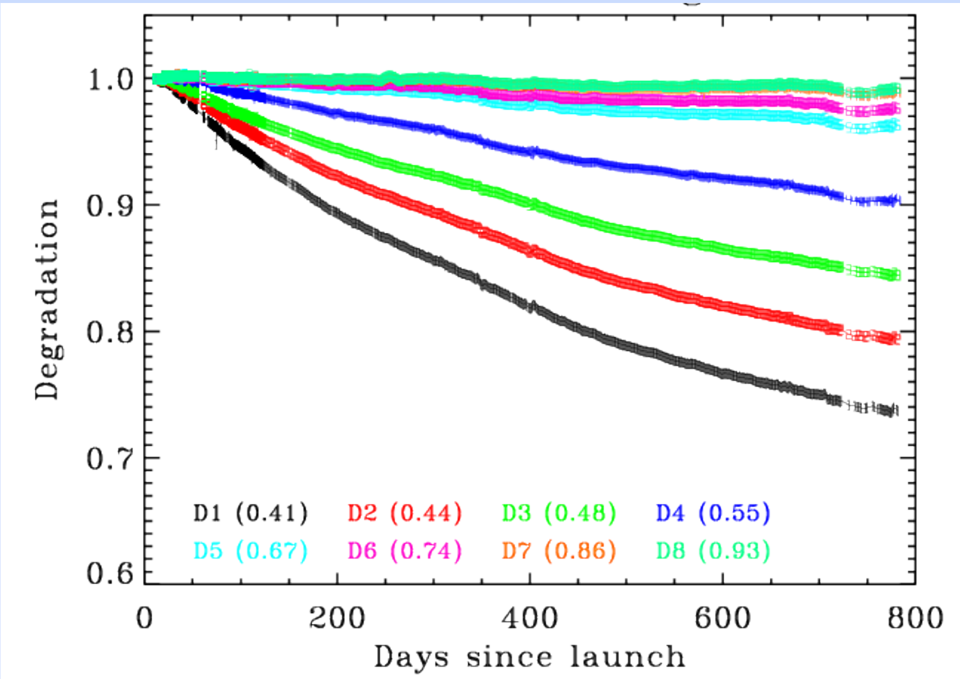
SD F-factor

$$F = \frac{L_{SD\_Comp}}{L_{SD\_Meas}}$$

On-orbit Performance

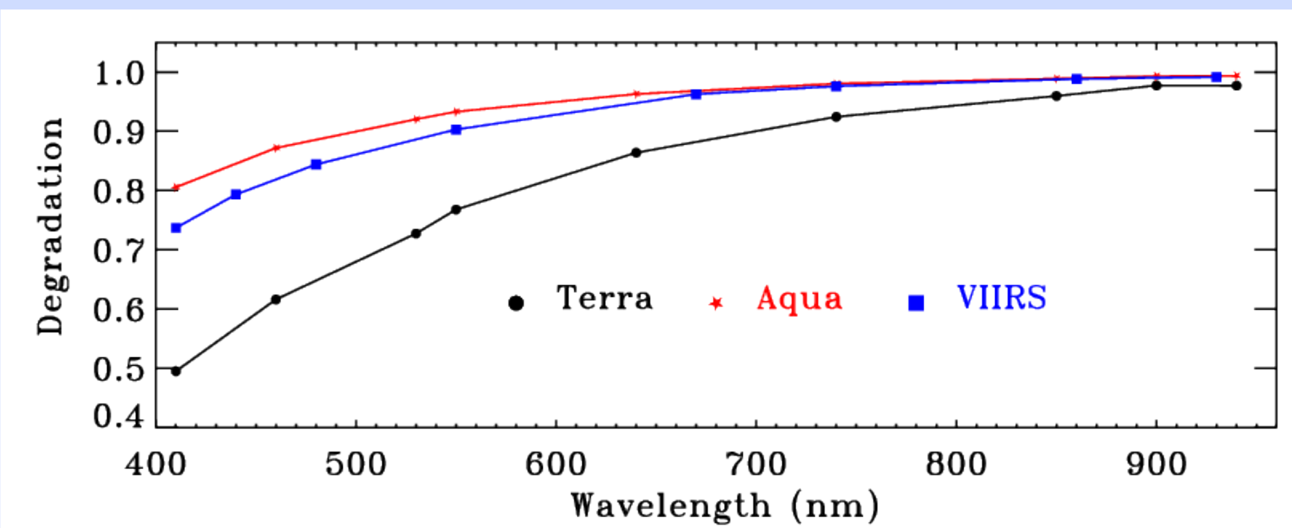
- **SD Degradation**
  - Larger degradation at shorter wavelengths
- **Changes in Spectral Band Response**
  - Large changes for several NIR/SWIR bands (caused by RTA mirrors contamination)
  - SNR performance continue to meet the design requirements a
- **Changes in Relative Spectral Response (RSR)**
  - Modulated RSR developed and applied to calibration and SDR data production

SD On-orbit Degradation



VIIRS SD Degradation (H-Factor)

MODIS & VIIRS SD Degradation



VIIRS has no SD door

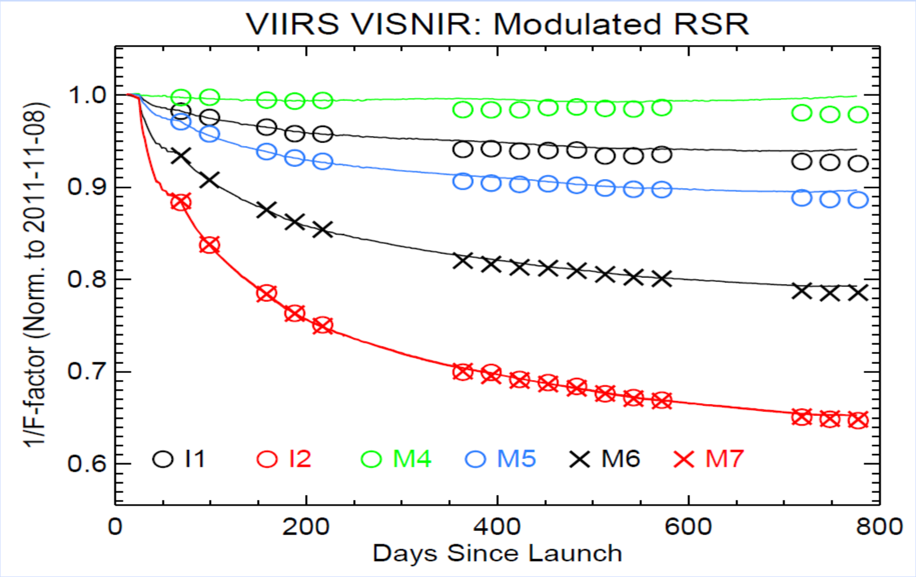
Terra MODIS SD door fixed at open since July 2003

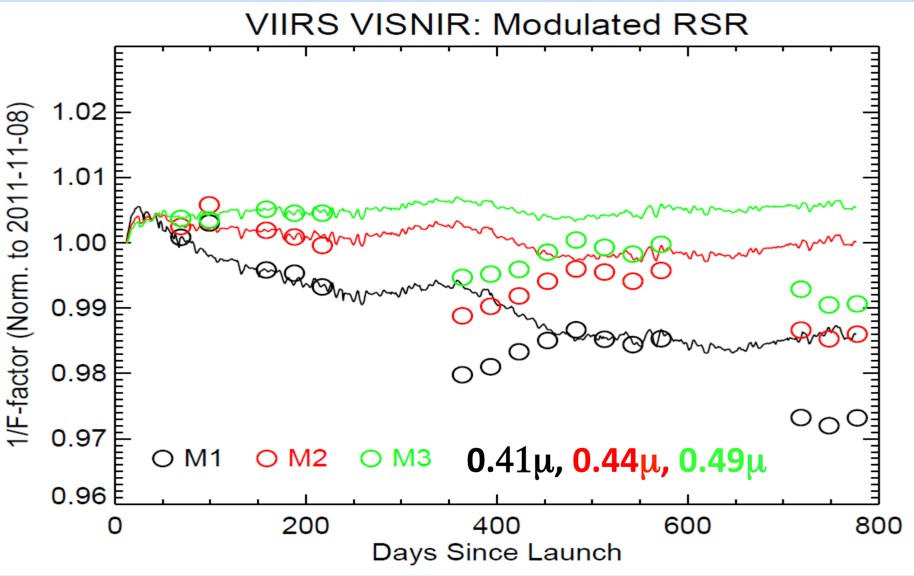
S-NPP VIIRS: 2 Yr

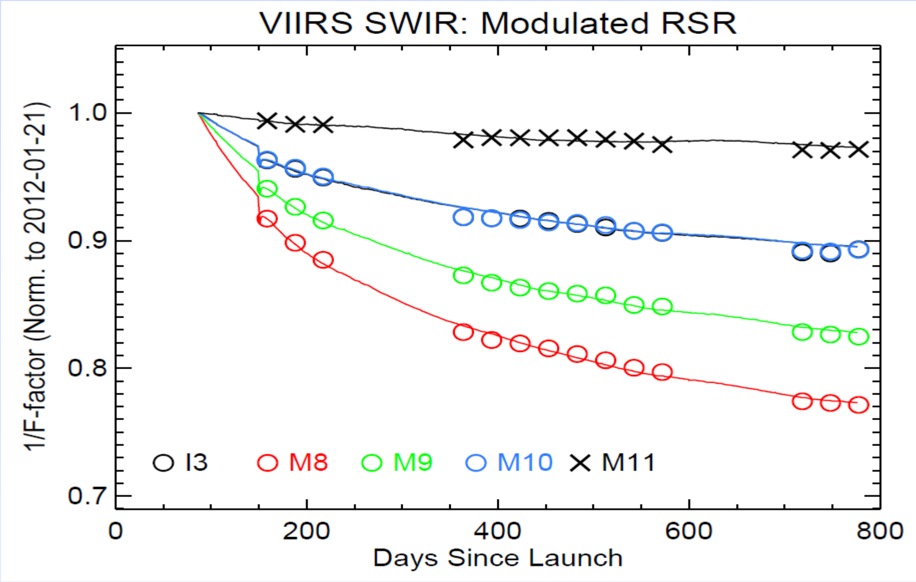
Aqua MODIS: 11.5 Yr

Terra MODIS: 14 Yr

Changes in Spectral Band Response





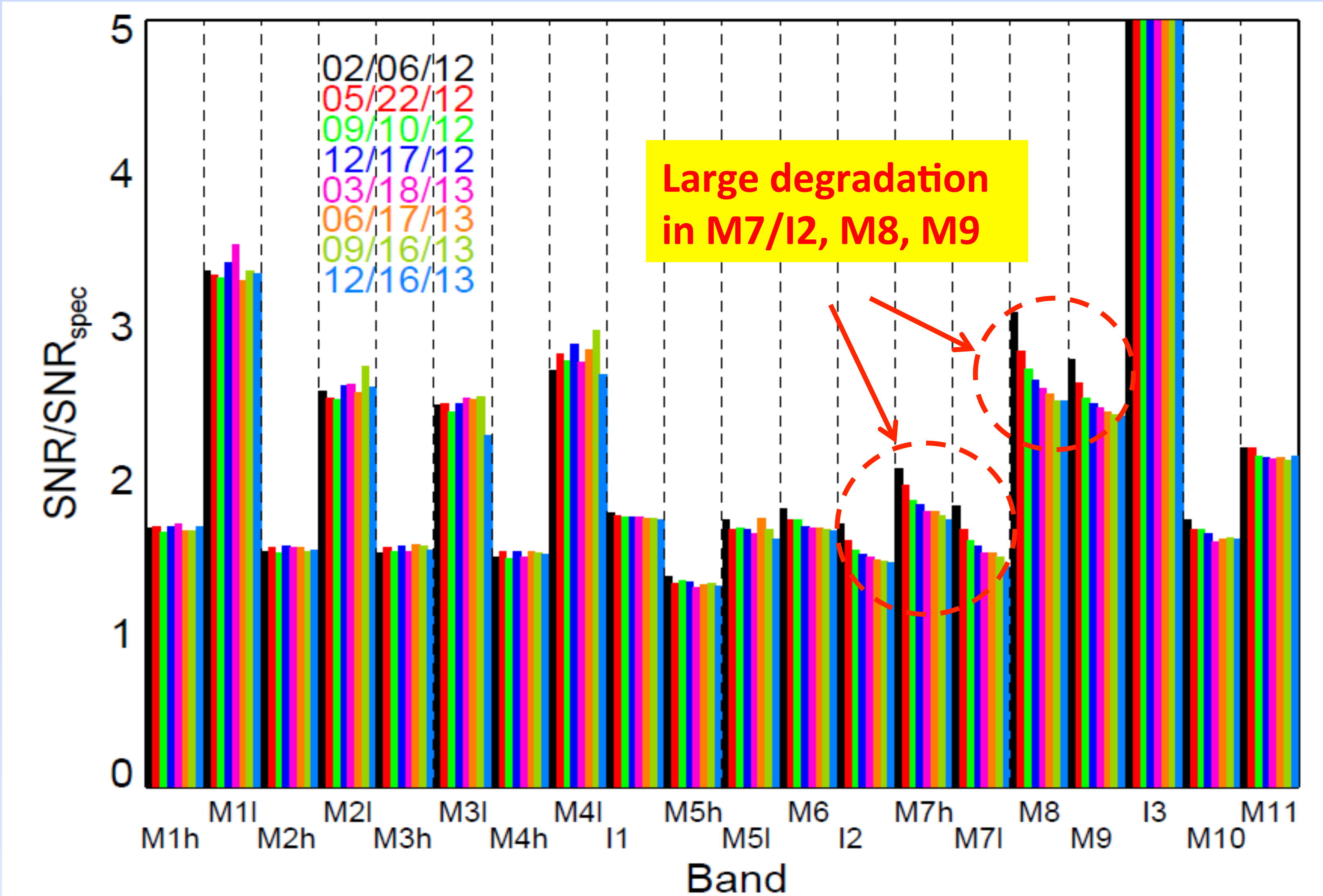


Large changes in NIR/SWIR response

Noticeable SD and Lunar calibration difference in VIS (M1-M3)

Improvements: SD calibration and lunar model

On-orbit SNR Performance

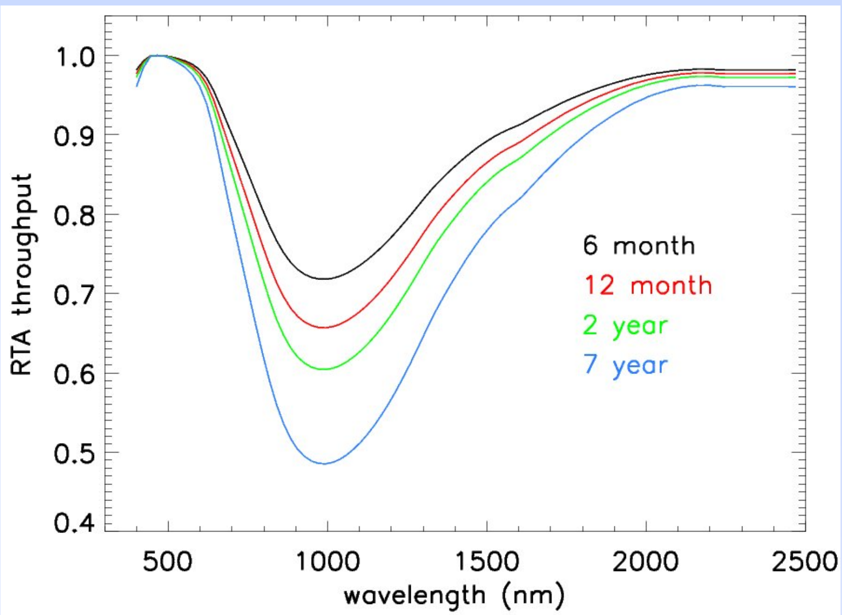


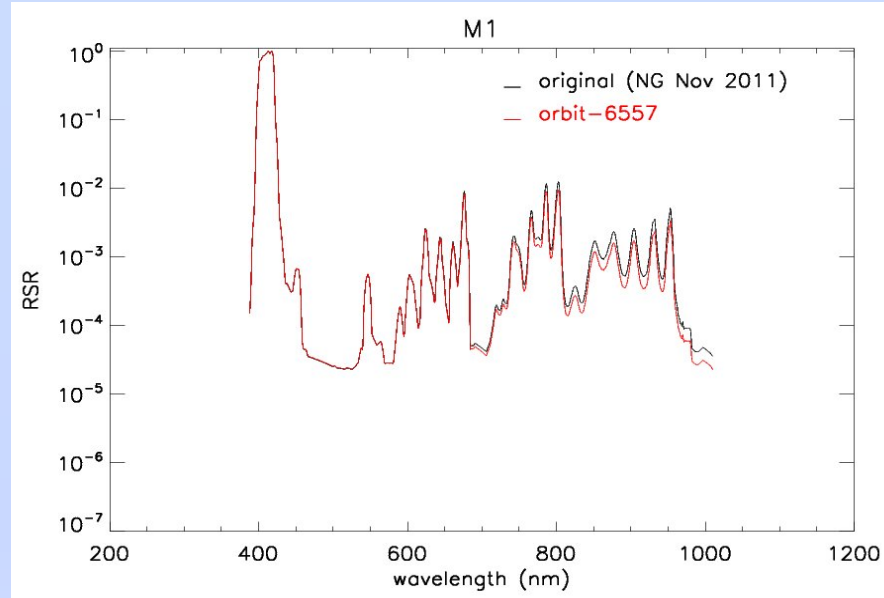
SNR/SNR$_{spec}$ > 1: performance better than specification

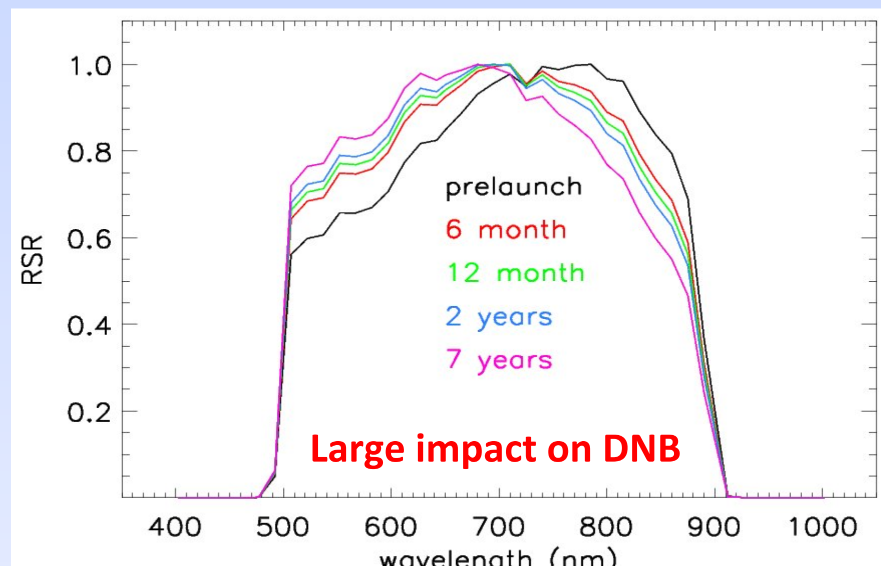
Changes in Relative Spectral Response

Mirror Degradation Impact on Sensor Relative Spectral Response

λ dependent optics degradation



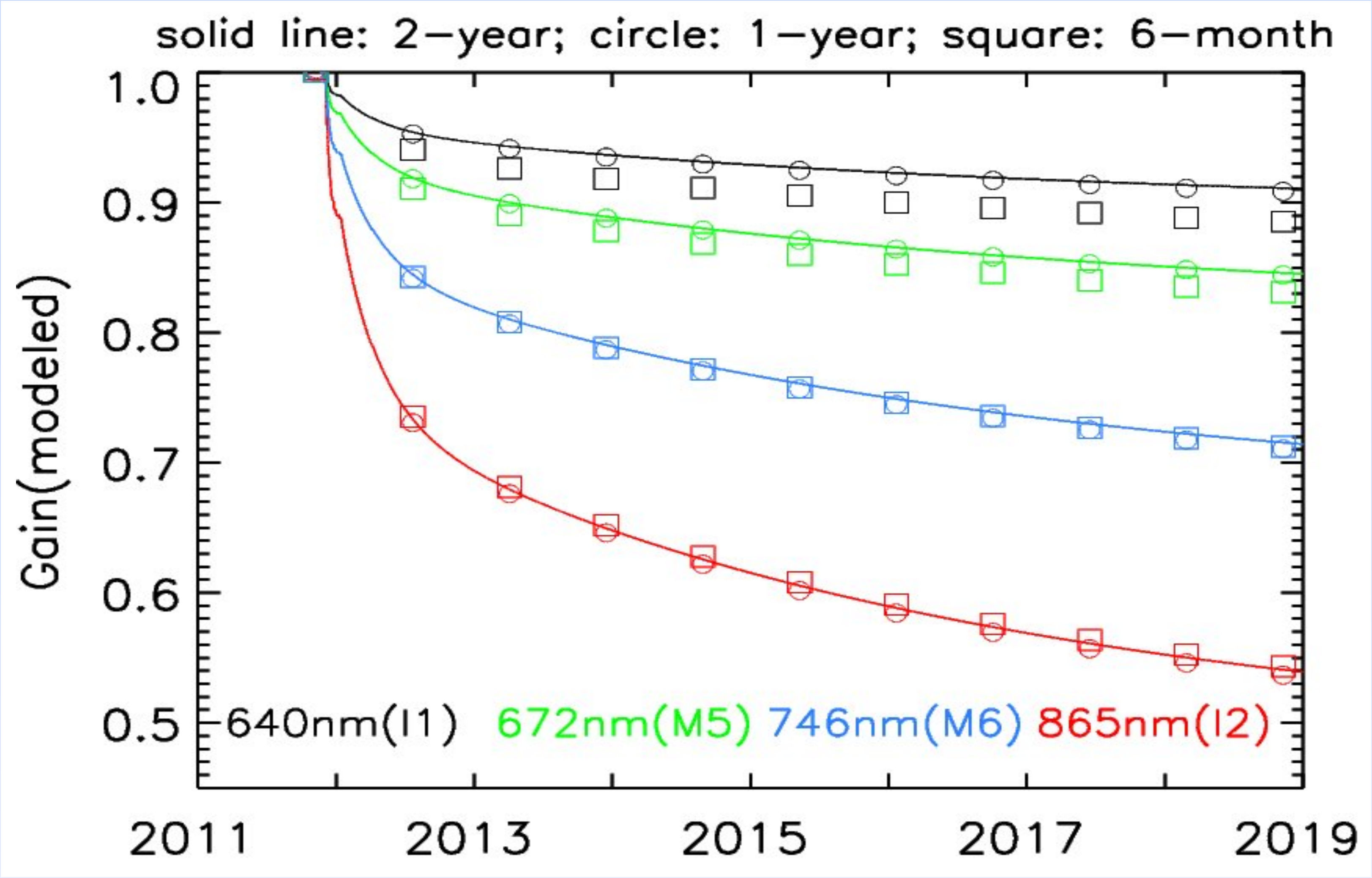




Modulate RSR has been applied to VIIRS calibration and data production

Changes in Relative Spectral Response

Mirror Degradation Modeling and Predication
(design lifetime: 7 years)

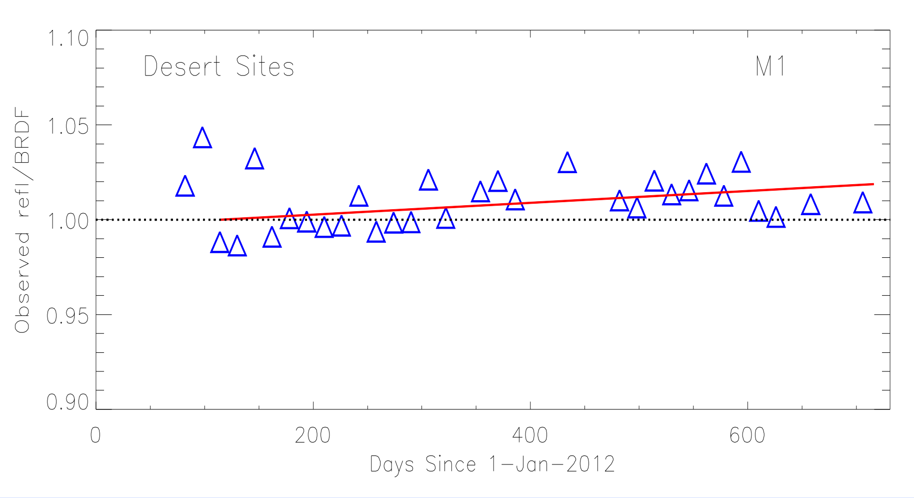


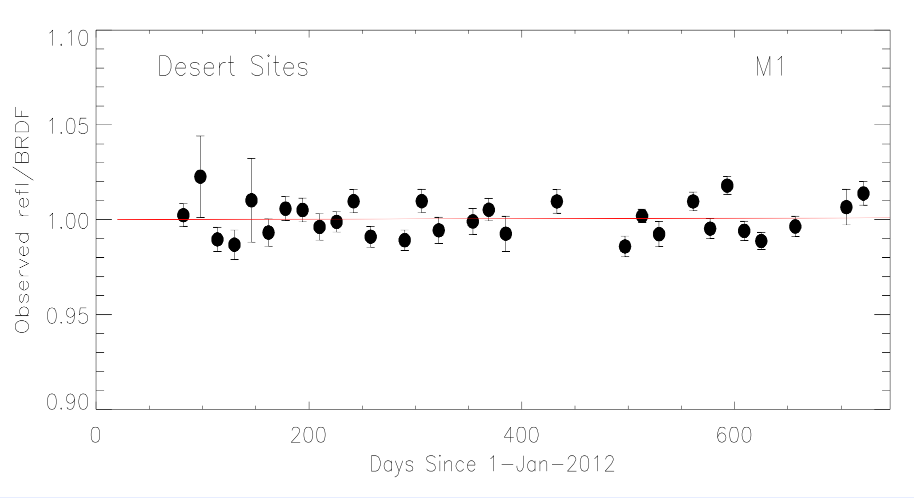
SDR Calibration Performance

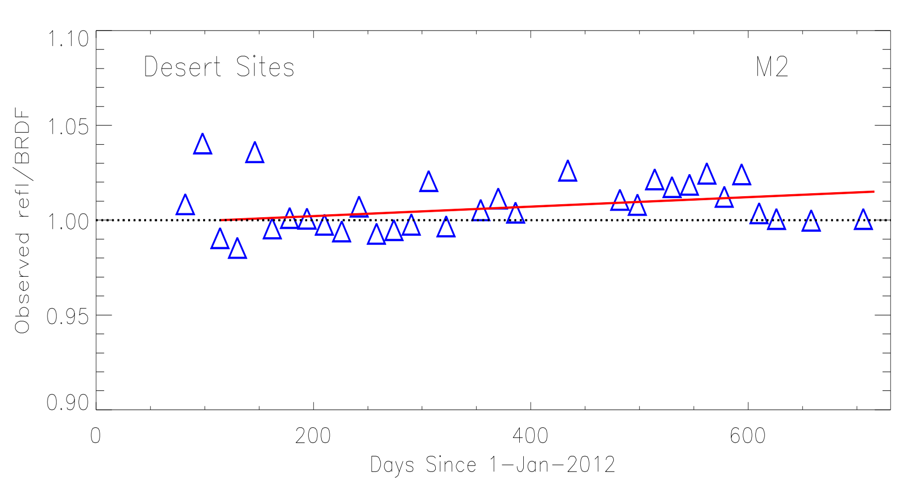
VIIRS reflectance trends over the Libya-4 desert

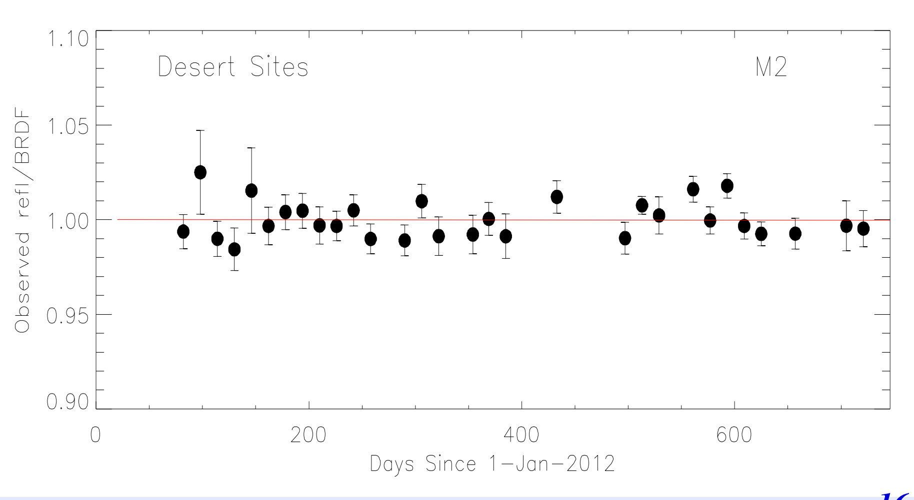
IDPS SDR (operational LUTs)

L-PEATE SDR (VCST LUTs)









SDR Calibration Performance

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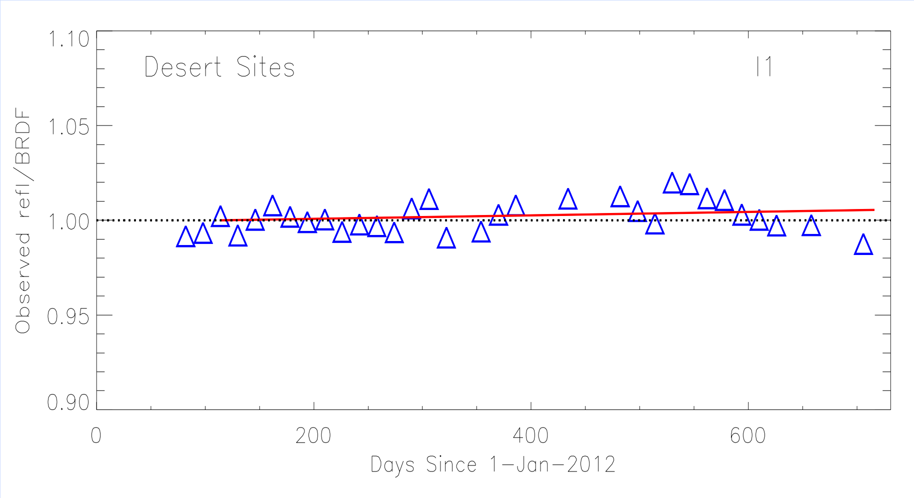
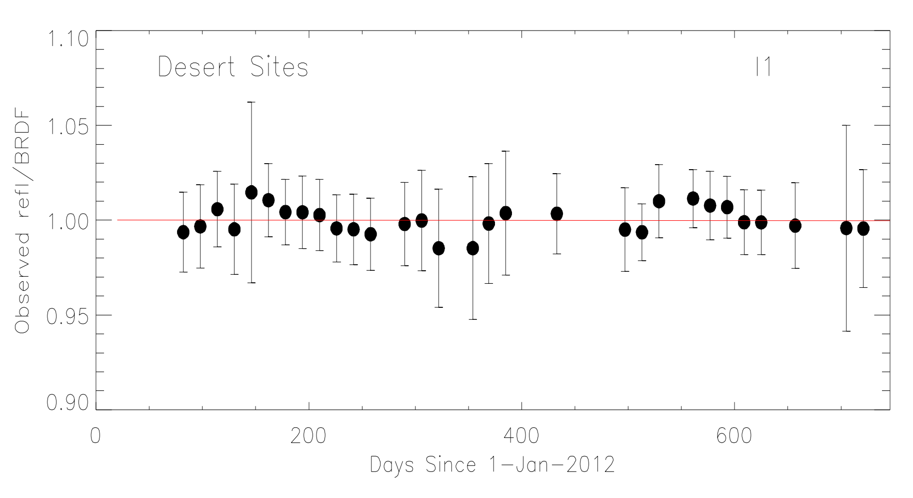
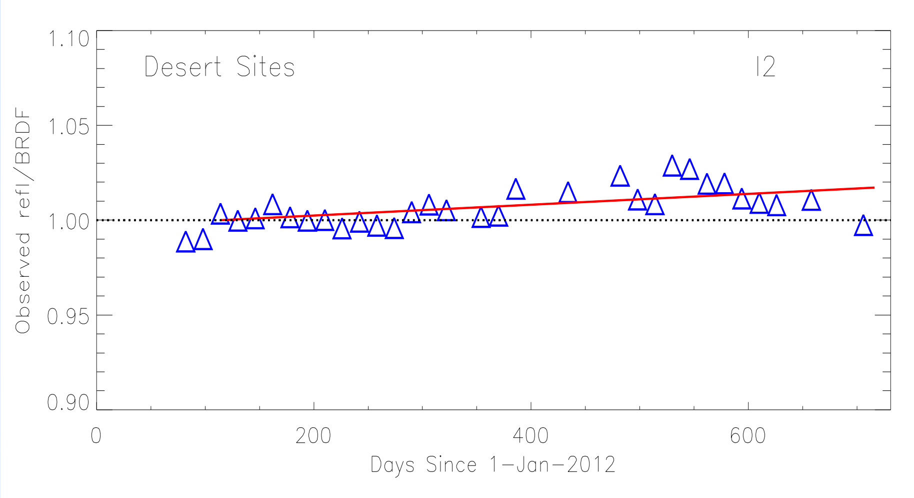
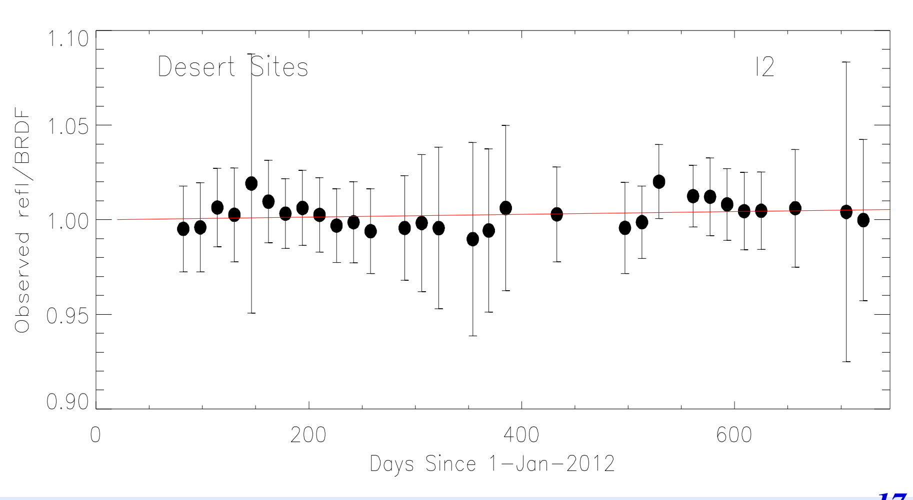








RS Cal UC Assessment Tool: Status and Path Forward

- **Completed an Excel tool to assess the CLARREO RS calibration error budget based on basic assumptions for the instrument design**
  - The tool is operational and gives adequate results when tested with known parameters (from MODIS);
  - For CLARREO the tool is operated with sample input (for illustration purposes only);
  - The error analysis implemented in the CLARREO tool is documented (an internal technical memo);
  - The tool design is flexible and allows easy implementation of new elements or the usage of alternative instrument designs and their respective uncertainty sources.
- **For a realistic estimate of the CLARREO error budget, a database should be complied with values of different UC contributors using results from instrument prototype or other sensors with similar design, including**
  - Solar attenuation mechanism and uncertainty – several alternative methods could be implemented with input from their respective uncertainty estimates;
  - Stray light at Earth and Sun view;
  - Spectral resolution and wavelength calibration uncertainty;
  - Detector response characterization and uncertainty (as a function of instrument conditions);
  - Polarization sensitivity uncertainty (as a function of instrument conditions)

TOA Reflectance Retrieval

Earth view reflectance $\rho_{EV}(\lambda)$:

$$\rho_{EV}(\lambda) = \frac{\pi L_{EVap}(\lambda)}{E_{sun}(\lambda, d_{SE})\cos(\theta_{SE})}.$$

Stray light radiance is presented as a fraction radiance at the aperture.

$$\boxed{\rho_{EV}(\theta_{EV},\lambda) = \frac{1}{\cos(\theta_{SE})}\frac{d_{SE}^2}{d_{Sun}^2}\frac{f(\lambda,\Delta t)g(\lambda,\Delta T)(1+s_{Sun})\tau_{atten}A_{atten}\Delta t_{eSun}}{\Omega_{ap}A_d(1+s_{EV})\Delta t_e}\times \frac{r(x,y,t_{EV})dn_{EV}(x,y)}{\sum_i\sum_{y'} r(x_i,y_i',t_{Sun})dn_{Sun}(x_i,y_i')},}$$

Detector response considered linear

where $dn(x,y) = DN(x,y) - DN_{BG}$;

and the reciprocal detector response is: $F(\lambda,t)c(\lambda,T_{INST}(t))r(\lambda,x,y,t)$

$F(\lambda,t)$ – characterized on orbit:

$F(\lambda,t_{EV})=f(\lambda,\Delta t)F(\lambda,t_{SV})$; $\Delta t=t_{SV}- t_{EV}$.

$c(\lambda,T_{INST})$ – from pre-launch characterization:

$c(\lambda,T_{EV})=g(\lambda,\Delta T)$. $c(\lambda,T_{SV})$; $\Delta T=T_{SV}-T_{EV}$.

$r(x,y,t)$ – flat field pix-to-pix response measured on orbit.

E_{sun} – Solar irradiance at the Earth surface.

$cos(\theta_{SE})$ – Angle of incidence of the solar light on the Earth.

L_{EVap} – Earth radiance at the aperture.

$s_{EV}(\lambda)$, $s_{Sun}(\lambda)$ – Stray light correction.

$\tau_{sys}(\lambda)$ - System transmittance of the common optical path between EV and Sun view.

$\tau_{pol}(\lambda)$ - Polarization sensitivity (EV).

A_d, Ω_{ap} – Field stop area and aperture solid angle.

$\tau_{atten}(\lambda)$ – Attenuator transmittance.

A_{atten} – Attenuator area.

Δt_e – Exposure time.

$dn(x,y)$ – Offset subtracted counts at pixel with coordinates x (spectral), y (spatial).

$c(\lambda, T_{INST})$ – Average (over pixels) detector response, characterized prelaunch.

$F(\lambda,t)$ – Correction to the detector response accounting for time dependent degradation. Evaluated on-orbit.

$r(x,y,t)$ – Flat field detector response (accounting for pix-to-pix variations) possibly a function of time. Evaluated on-orbit.

TOA Reflectance Retrieval Uncertainty

Earth reflectance uncertainty:

$$\frac{\delta\rho_{EV}}{\rho_{EV}} = [\left(\frac{\delta s_{Sun}}{1+s_{Sun}}\right)^2 + \left(\frac{\delta s_{EV}}{1+s_{EV}}\right)^2 +$$

Stray light correction uncertainty

$$\left(\frac{\delta\tau_{atten}}{\tau_{atten}}\right)^2 + \left(\frac{\delta\tau_{pol}}{\tau_{pol}}\right)^2 + \left(\frac{\delta A_d}{A_d}\right)^2 + \left(\frac{\delta A_{atten}}{A_{atten}}\right)^2 + \left(\frac{\delta\Omega_{ap}}{\Omega_{ap}}\right)^2 +$$

Uncertainties on instrument characteristics which can only be estimated pre-launch.

$$\left(\frac{\delta f}{f}\right)^2 + \left(\frac{\delta g}{g}\right)^2 + \left(\frac{\delta r_{xy}}{r_{xy}}\right)^2 + \left(\frac{\sum_{i,y}(\delta r_{x_i y_i})^2}{(\sum_{i,y} r_{x_i y_i})^2}\right) +$$

δg - Uncertainty on the detector response as function of instrument conditions – estimated pre-launch. Possible wavelength and spectral resolution differences between EV and Sun view should be included in this estimate.

δf - Uncertainty in the detector degradation estimate at t_{EV} based on t_{Sun}. Wavelength and spectral differences to be considered.

δr - Uncertainty on flat field response (to account for pix-to-pix variations).

Signal noise: shutter noise, read out noise, dark current noise, ADC quantization noise

$$+\left(\frac{\delta dn_{EV}}{dn_{EV}}\right)^2 + \left(\frac{\sum_{i,y}(\delta dn_{Sun})^2}{(\sum_{i,y} dn_{Sun})^2}\right) +$$

Spectral sampling and wavelength calibration uncertainty.

$$+2\left(\frac{\partial E_{Sun}/\partial\lambda}{E_{Sun}}\right)^2 \delta\lambda^2 + 2\left(\frac{\delta\Delta\lambda}{\Delta\lambda}\right)^2 + \left(\frac{\delta\Delta t_{eratio}}{\Delta t_{eratio}}\right)^2$$

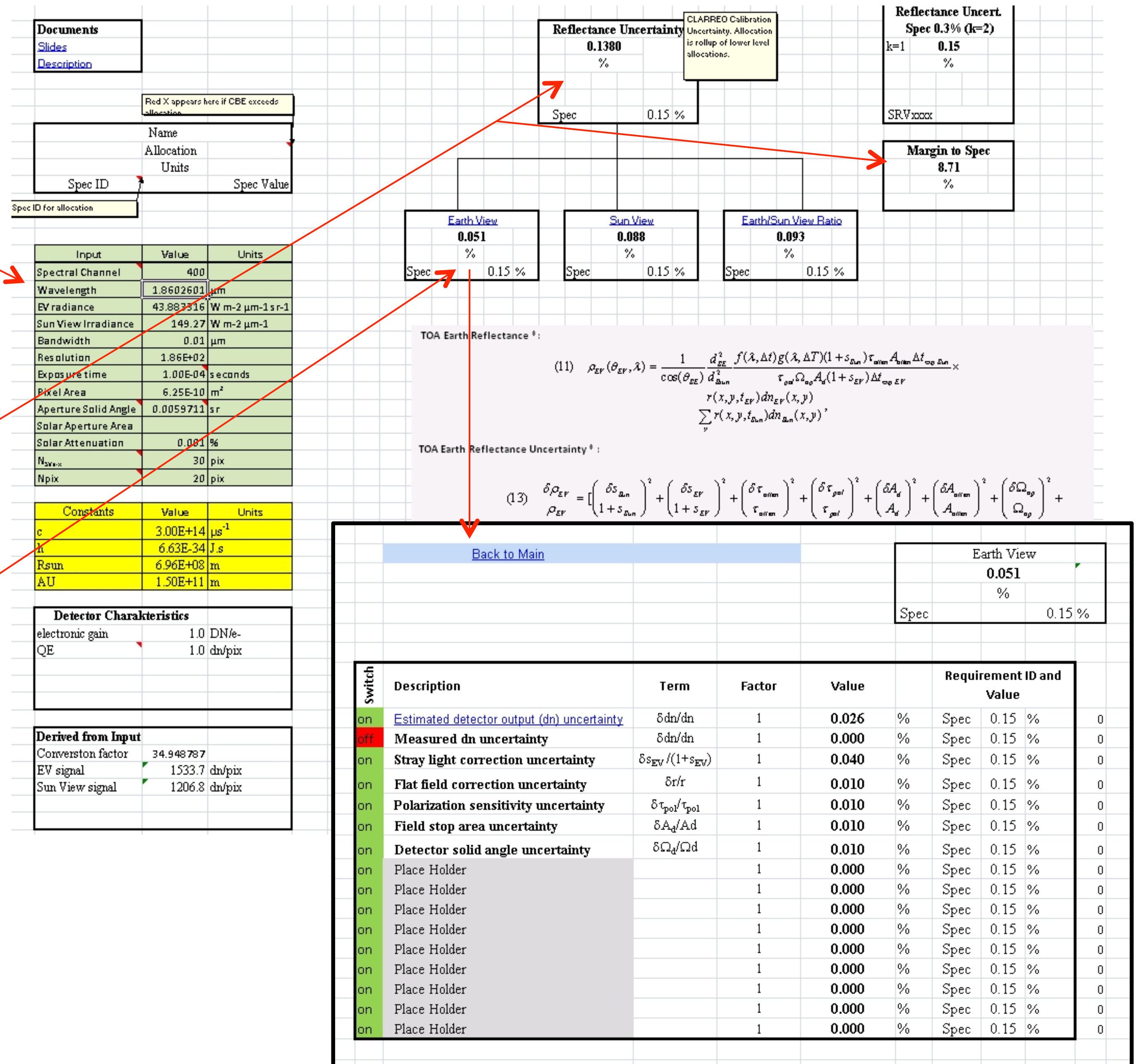
$$+\left(\frac{\Delta\rho_{nonlin}}{\rho_{EV}}\right)^2]^{-1/2}$$

Exposure time (EV /Sun View) ratio uncertainty.

Uncertainty from detector nonlinearity

Tool Interface

- Input:
  - ✓Instrument parameters
  - ✓Spectral channel
- Output:
  - ✓TOA reflectance uncertainty and margin to spec.
  - ✓Uncertainty calculated for each view separately
  - ✓Each view uncertainty is a combination of lower level uncertainties



Input	Value	Units
Spectral Channel	400	
Wavelength	1.8602601	µm
EV radiance	43.883316	W m-2 µm-1 sr-1
Sun View Irradiance	149.27	W m-2 µm-1
Bandwidth	0.01	µm
Resolution	1.86E+02	
Exposure time	1.00E-04	seconds
Pixel Area	6.25E-10	m²
Aperture Solid Angle	0.0059711	sr
Solar Aperture Area		
Solar Attenuation	0.001	%
N_{sws-x}	30	pix
Npix	20	pix

Constants	Value	Units
c	3.00E+14	µs^{-1}
h	6.63E-34	J.s
Rsun	6.96E+08	m
AU	1.50E+11	m

Detector Charakteristics		
electronic gain	1.0	DN/e-
QE	1.0	dn/pix

Derived from Input		
Converstion factor	34.948787	
EV signal	1533.7	dn/pix
Sun View signal	1206.8	dn/pix

Switch	Description	Term	Factor	Value		Requirement ID and Value			
on	Estimated detector output (dn) uncertainty	δdn/dn	1	0.026	%	Spec	0.15	%	0
off	Measured dn uncertainty	δdn/dn	1	0.000	%	Spec	0.15	%	0
on	Stray light correction uncertainty	$\delta s_{EV}/(1+s_{EV})$	1	0.040	%	Spec	0.15	%	0
on	Flat field correction uncertainty	δr/r	1	0.010	%	Spec	0.15	%	0
on	Polarization sensitivity uncertainty	$\delta\tau_{pol}/\tau_{pol}$	1	0.010	%	Spec	0.15	%	0
on	Field stop area uncertainty	$\delta A_d/Ad$	1	0.010	%	Spec	0.15	%	0
on	Detector solid angle uncertainty	$\delta\Omega_d/\Omega d$	1	0.010	%	Spec	0.15	%	0
on	Place Holder		1	0.000	%	Spec	0.15	%	0
on	Place Holder		1	0.000	%	Spec	0.15	%	0
on	Place Holder		1	0.000	%	Spec	0.15	%	0
on	Place Holder		1	0.000	%	Spec	0.15	%	0
on	Place Holder		1	0.000	%	Spec	0.15	%	0
on	Place Holder		1	0.000	%	Spec	0.15	%	0
on	Place Holder		1	0.000	%	Spec	0.15	%	0
on	Place Holder		1	0.000	%	Spec	0.15	%	0
on	Place Holder		1	0.000	%	Spec	0.15	%	0

Summary

- VIIRS continues to operate and calibrate well
  - Use of on-board calibrators (OBC): SD, SDSM, BB and lunar observations
  - On-orbit changes in sensor response are frequently and accurately tracked by the OBC
  - Data quality maintained via frequent calibration LUT updates
- Overall VIIRS on-orbit performance meets the design requirements
  - SDR quality: validated
  - Future improvements and dedicated calibration effort (e.g. modulated RSR)
- Importance of CALRREO to missions like Terra, Aqua, S-NPP, and JPSS

VIIRS and MODIS Spectral Bands

VIIRS Band	Spectral Range (um)	Nadir HSR (m)	MODIS Band(s)	Range	HSR
DNB	0.500 - 0.900				
M1	0.402 - 0.422	750	8	0.405 - 0.420	1000
M2	0.436 - 0.454	750	9	0.438 - 0.448	1000
M3	0.478 - 0.498	750	3 10	0.459 - 0.479 0.483 - 0.493	500 1000
M4	0.545 - 0.565	750	4 or 12	0.545 - 0.565 0.546 - 0.556	500 1000
I1	0.600 - 0.680	375	1	0.620 - 0.670	250
M5	0.662 - 0.682	750	13 or 14	0.662 - 0.672 0.673 - 0.683	1000 1000
M6	0.739 - 0.754	750	15	0.743 - 0.753	1000
I2	0.846 - 0.885	375	2	0.841 - 0.876	250
M7	0.846 - 0.885	750	16 or 2	0.862 - 0.877 0.841 - 0.876	1000 250
M8	1.230 - 1.250	750	5	SAME	500
M9	1.371 - 1.386	750	26	1.360 - 1.390	1000
I3	1.580 - 1.640	375	6	1.628 - 1.652	500
M10	1.580 - 1.640	750	6	1.628 - 1.652	500
M11	2.225 - 2.275	750	7	2.105 - 2.155	500
I4	3.550 - 3.930	375	20	3.660 - 3.840	1000
M12	3.660 - 3.840	750	20	SAME	1000
M13	3.973 - 4.128	750	21 or 22	3.929 - 3.989 3.929 - 3.989	1000 1000
M14	8.400 - 8.700	750	29	SAME	1000
M15	10.263 - 11.263	750	31	10.780 - 11.280	1000
I5	10.500 - 12.400	375	31 or 32	10.780 - 11.280 11.770 - 12.270	1000 1000
M16	11.538 - 12.488	750	32	11.770 - 12.270	1000

1 DNB

14 RSB
(0.4-2.3 μm)

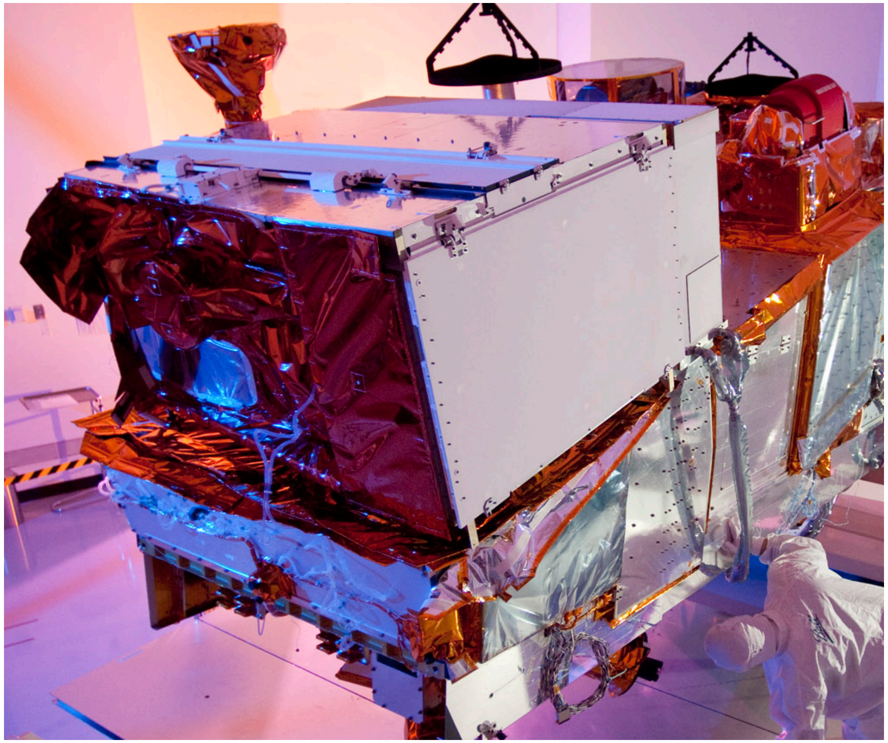
Dual gains:
M1-M4, M6, M7
M12

7 TEB

VIIRS Reflective Solar Bands (RSB)

Description

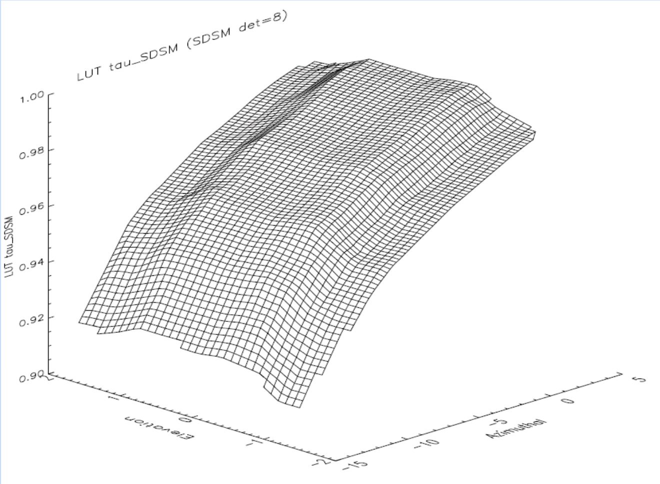
- Purpose: Global observations of land, ocean, & atmosphere parameters at high temporal resolution (~ daily)
- Predecessor Instruments: AVHRR, OLS, SeaWiFS, MODIS
- Spectral range: 22 bands between 0.4 µm and 12.5 µm
- Spatial resolution: 375 and 750 m
- Swath Width: 3000 km



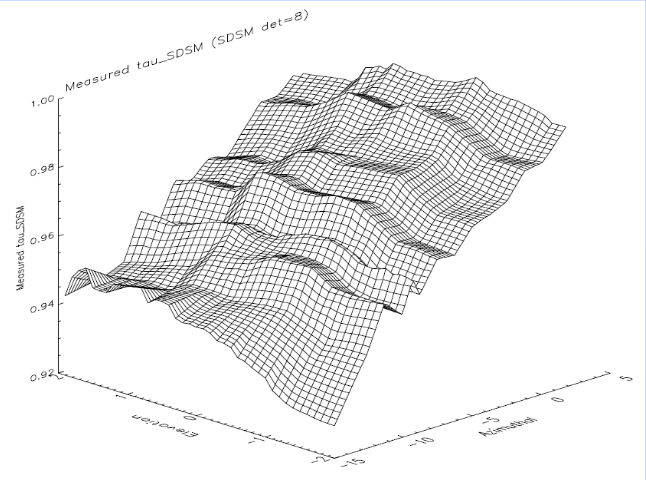
Key Features

- MODIS-like on-board calibrators
- 16 moderate (radiometric), 5 imaging, and 1 day/night bands
- Dual gains (7 bands)
- VIS/NIR, SMIR, and LWIR focal plane assemblies (FPA)
- Pixel aggregations and bowtie deletion

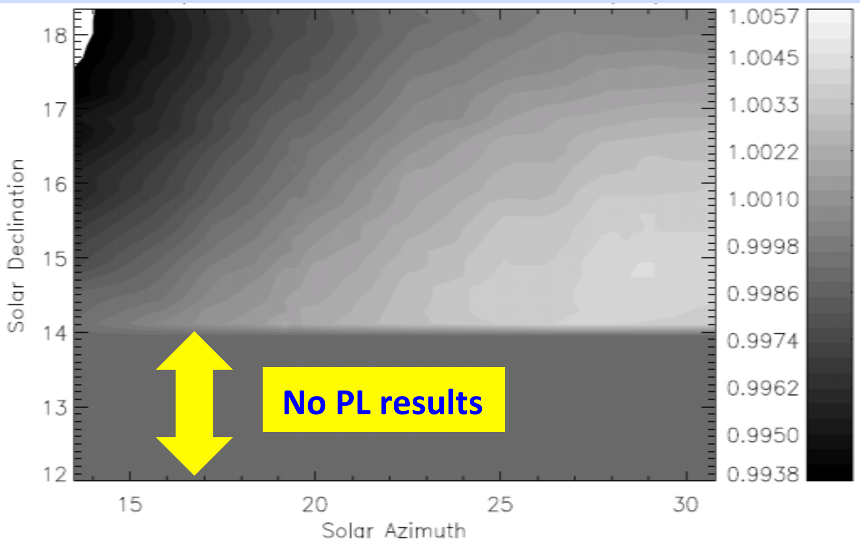
Yaw Maneuvers: Results and Applications



SDSM Sun view screen transmission: Fine structure



Ratio of Pre-launch LUT to Yaw Results (SD screen transmission x BRF)

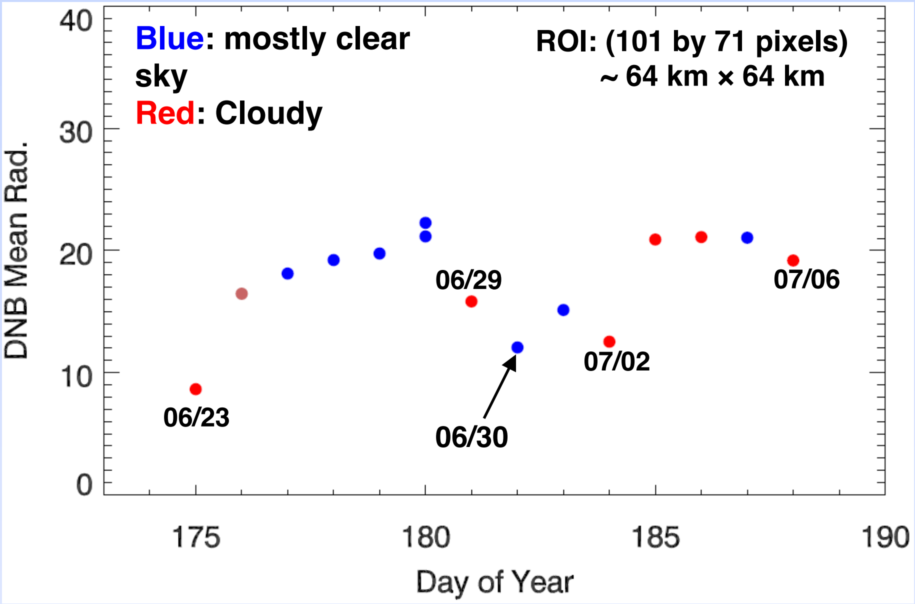


SDSM Sun view screen transmission function derived from yaw maneuvers has been used in SDR calibration

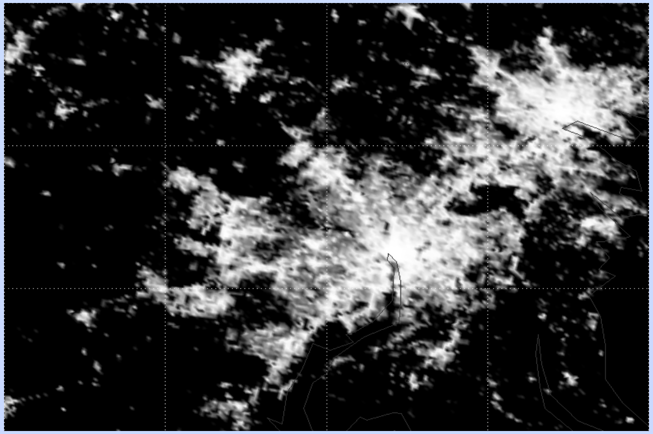
The LUT for SD screen transmission x BRF derived from yaw maneuvers has also been applied recently to SDR calibration

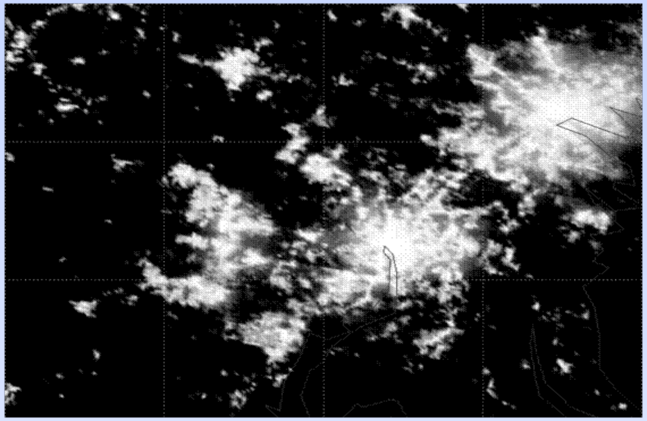
DNB: Many New Applications

- The Day/Night Band has been used to detect a major power outage in the Washington, DC on the night of the Direcho storm on June 29, 2012.
- An analysis of the data after the storm showed that most areas had power restored within 3 days.



VIIRS DNB radiance time series before and after the power outage (6/29) shows that most of the power was restored in three days.





VIIRS DNB of the Washington/Baltimore area on June 26th (top)and June 30th.
The suburbs west of DC and Baltimore, in particular show dark areas.

From GSICS presentation (Cao and Xiong)